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ABSTRACT

Structure mapping theory is a way of characterizing analogies and certain classes of metaphors. The central claim of this paper is that all analogies and many metaphors are fundamentally devices for mapping relational structures from one domain to another. This theory differs from other theories in postulating that the interpretation rules for analogies and relational metaphors are based on predicate structure rather than on feature salience or mental distance. Two experiments tested the interpretive predictions of the structure mapping theory as well as those derivable from A. Ortony's salience imbalance theory of metaphor. Subjects, college students, were asked to interpret metaphors and rate their aptness and "metaphoricity," after first writing out descriptions of all the object terms used in the metaphors. Results supported the structure mapping theory of metaphor. Specifically, the experiments revealed that: (1) metaphor interpretations were more relational than the object descriptions on which they were based, suggesting that the subjects found metaphors more apt to the extent that they could find a relational system to map from base to target object; and (2) adult subjects produced structural interpretations of metaphorical comparisons when possible and judged the aptness of the metaphors according to their relationality, suggesting that metaphoric development can be described as the gradual development of relational focus. (A seven-page reference list is included.) (FL)

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EVIDENCE FOR A STRUCTURE-MAPPING THEORY OF ANALOGY AND METAPHOR

by

Dedre Gentner

December 1986

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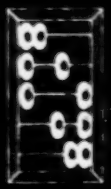

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Two experiments are described that test the interpretation predictions of the structure-mapping theory as well as those derivable from Ortony's(1979) salience imbalance theory of metaphor. Subjects were asked to interpret metaphors and rate their aptness and metaphoricity, after first writing out descriptions of all the object terms used in the metaphors. The results supported the structure-mapping account.

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EVIDENCE FOR A STRUCTURE-MAPPING THEORY OF ANALOGY AND METAPHOR

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EVIDENCE FOR A STRUCTURE-MAPPING THEORY OF ANALOGY AND METAPHOR

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Abstract

This paper presents evidence for the structure-mapping theory of analogy and metaphor. The central claim is that all analogies, and many metaphors, are fundamentally devices for mapping relational structures from one domain to another. This theory differs from other approaches in postulating that the interpretation rules for analogies and relational metaphors are based on predicate structure, rather than on feature salience or mental distance.

Two experiments are described that test the interpretation predictions of the structure-mapping theory as well as those derivable from Ortony's (1979) salience imbalance theory of metaphor. Subjects were asked to interpret metaphors and rate their aptness and metaphoricity, after first writing out descriptions of all the object terms used in the metaphors. The results supported the structure-mapping account.

"And I cherish more than anything else the Analogies, my most trustworthy masters." (Johannes Kepler, quoted in Polya, 1973).

Analogy and metaphor pose a challenge to cognitive research. There is general agreement that analogy plays a key role in creative thinking and problem solving. A case can be made that implicit metaphors structure most of our thought (Lakoff & Johnson, 1980). But analogy and metaphor have proven difficult to characterize in conventional accounts of similarity. A theory of analogy and metaphor must deal with issues like (1) how are analogy and metaphor different from literal similarity; (2) what are the interpretation rules for analogy and metaphor; (3) what makes an analogy or metaphor apt?

In this paper, I offer the structure-mapping theory as a way of characterizing analogies and certain classes of metaphor. I first present the structure-mapping theory, illustrating it with examples, and then use the theory to differentiate analogy and metaphor from other types of comparisons and from each other. Finally I describe two studies testing the predictions of the theory as to how interpretations of analogy and metaphor are derived from prior knowledge of the two terms of the comparison. These predictions are contrasted with predictions derived from another current approach, Ortony's (1979) salience imbalance theory.

To motivate the discussion, consider the following three comparisons:

(1) Alcohol is like water.

(2) Heat is like water.

(3) For we are as water spilt on the ground which cannot be gathered up again.

Statement (1) is a literal similarity comparison which tells us that much of the information we have stored about water can be applied to

alcohol. Statements (2) and (3) convey nonliteral similarity; they would probably be categorized as analogy (2) and metaphor (3). The first job of a theory of analogy is to characterize the difference between a metaphor or analogy[1] on the one hand and literal similarity on the other. The simplest possibility---that metaphor and analogy are merely very weak similarity statements---can be ruled out. Tourangeau and Sternberg (1981) correlated subjects' aptness ratings of metaphors with their ratings of the similarity of the base and target objects. The metaphors considered most apt were those for which the base and target were neither extremely dissimilar nor extremely similar. Thus, it appears that the distinction between literal similarity and analogy is not simply one of degree of likeness, or number of matching features.

In the structure-mapping theory (Gentner, 1980, 1982, 1983, 1986; Gentner & Gentner, 1983) analogy is distinguished from literal similarity by the kinds of matching features. The basic intuition is that an analogy

---

[1]The terms "analogy", "metaphor" and "simile" are all rather loosely used to refer to nonliteral similarity comparisons. Similes are distinguished from metaphors by the surface characteristic that they contain an explicit comparative term such as "like." Developmental evidence suggests that, although the simile form signals a comparison more clearly, the ultimate interpretation rules are the same for simile as for metaphor (Reynolds and Ortony, 1980). I will combine simile with other nonliteral comparisons here.

Analogy and metaphor differ more subtly: "analogy" conveys an explanatory-predictive purpose, while "metaphor" conveys an expressive or aesthetic intent. Also, "analogy" is sometimes taken to include weak literal similarity; "metaphor" is always nonliteral. I will confine the term "analogy" to its nonliteral sense. Thus "analogy" will mean an explanatory-predictive nonliteral comparison, and "metaphor" will mean an expressive-aesthetic nonliteral comparison. There are some interpretation differences that result from the explanatory-expressive distinction. Nevertheless, relational metaphor and analogy are more alike than different. In this paper, I will consider analogy, relational metaphor, and simile together in contrast to literal similarity. For more detailed discussions of the differences between metaphor and analogy, see Miller (1979) and Gentner (1982).

is an assertion that a relational structure that normally applies in one domain can be applied in another domain. This leads to a simple but powerful distinction among predicate types that allows us to state which ones will be mapped in an analogy. Metaphor is more complex than analogy; as discussed below, there are a number of ways that metaphors can be constituted. However, there is a large class of metaphors -- which I will call 'relational' metaphors -- that follows the same structure-mapping rules as analogy. (Example (3) above is such a metaphor). Thus, although the theory is primarily aimed at explaining analogy, it also applies to relational metaphor.

Before laying out the structure-mapping theory in detail, a few preliminaries are necessary.

1. To capture the necessary distinctions, a rich propositional representation of knowledge is required, such as the networks of nodes and predicates used here (cf. Collins & Quillian, 1969; Miller & Johnson-Laird, 1976; Norman & Rumelhart, 1975; Palmer, 1978; Rumelhart & Ortony, 1977; Schank & Abelson, 1977). The nodes represent concepts treated as wholes; the predicates applied to the nodes express propositions about the concepts.

2. In order to capture the distinction between object descriptions and rational structure, I make a distinction between object-attributes and relations. Attributes are predicates taking one argument in the domain; for object-attributes, that argument is an object in the domain. Relations are predicates taking two or more arguments. For example, COLLIDE (x,y) is a relation, while YELLOW (x) is an attribute. It is important to note that the fundamental distinction here is between object-descriptions and relational structure. The

distinction between attributes and relations is only an approximation to this distinction (See Gentner, 1986a, for a longer discussion). The advantages of this formulation are that it is objectivity statable and easily computed.

In using the attribute-versus-relation distincion, the one-place versus n-place distinction must be made over objects in the domain. Only relations that apply within the domain of discourse are relevant to the analogy process. Thus, a relation such as LARGER THAN (sun, planet) that applies between two objects in the base (or target) domain, is processed as a relation in an analogical mapping. In contrast, a predicate such as LARGE (sun), which takes only one argument in the domain of discourse, is treated as a one-place predicate, even though its interpretation may involve an implicit extra-domain comparison LARGER THAN (sun, typical star). (See Palmer, 1978; Rips & Turnbull, (1980); Smith & Osherson, 1984.)

3. A second important structural distinction is the order of a predicate. The order of a predicate is defined as follows: (1) constants and functions on constants have order 0; (2) the order of a predicate is 1 + the maximum order of its arguments. Thus, a first-order predicate is one whose arguments are objects. A second-order predicate is one for which at least one argument is a first-order predicate, and so on. For example, if COLLIDE (x,y) and STRIKE (y,z) are first-order predicates, CAUSE [COLLIDE (x,y), STRIKE (y,z)] is a second-order predicate.

It is important to note that these distinctions among predicate types apply to psychological representations. Logically, the same proposition can be expressed in many formally equivalent ways. For example, a relation R(a,b,c) can perfectly well be represented as a

one-place predicate Q(x), where Q(x) is defined to be true just in case R(a,b,c) is true. Similarly, for any higher-order predicate structure, a first-order predicate can be defined that will be logically equivalent. Does this invalidate the relation-attribute distinction, or the first-order versus higher-order distinction among relations? It does not, because our interest is not in all the ways a domain could logically be represented, but in how it is psychologically represented at a given time for a given person. The assumption I make is that there is a psychological difference between, for example, believing that the sun is a large object of its class and believing that it is larger than a given planet. The structure-mapping theory concerns the way the rules of analogy operate to produce an analogy interpretation given the person's -- or machine's -- current representations of the base and target.

Structure-mapping: Interpretation Rules

With these preliminaries, we can now set forth the implicit interpretation rules for analogy: (1) relations between objects are mapped from base to target, while object-attributes are discarded; and (2) the particular relations mapped are determined by systematicity, as defined by the existence of higher-order constraining relations that can themselves be mapped.[2]

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[2] In the simplest case, the person hearing the analogy is told the object correspondences; then the intended inferences in the target can be derived simply by mapping across the predicate structure from the base, according to the rules of analogy. However, even if the person is not told the object correspondences, she can derive what they must be by matching known relations in the two domains. Either way, once a set of object correspondences is chosen, then further predicates from the base can be mapped, even predicates previously not known in the target domain. Thus new predictions can be generated.

This can be made more specific. Imagine a person hearing an analogy "A T is (like a) B."[3] Understanding the analogy involves finding a mapping of the object nodes of B onto object nodes of T such that relations from B can be carried into T:

$$M: \ b_i \dashrightarrow t_i$$

(Here the base domain B is represented in terms of object nodes b_1, b_2, ..., b_n and predicates such as A, R, R'. The target domain is represented in terms of some object nodes t_1, t_2, ..., t_m. with few additional predicates.) Object attributes are <u>not</u> mapped.

$$A(b_i) \ \not\dashrightarrow A\ (t_i)$$

The implicit analogical contract is that object correspondences between the two domains are determined <u>not</u> by any intrinsic similarity between the objects, but by their roles in the relational structure.

Analogical inferences are derived by carrying relations across from base to target:

$$M: \ R(b_i,b_j) \ \dashrightarrow \ R(t_i,t_j)$$

Here $R(b_i,b_j)$ is a relation that holds in the base domain B.

The systematicity principle determines which relations will be mapped. The desired mapping is one in which a deep predicate structure of the target can be carried into the base and matched--or partially matched--with a predicate system in the base.

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[3]As mentioned above, we ignore here the distinction between metaphor and simile.

$$M: \quad R'[(R_1(b_i, b_j), R_2(b_k, b_l)] \rightarrow$$

$$R'[(R_1(t_i, t_j), R_2(t_k, t_l)]$$

Here R_1 and R_2 are first-order relations and R' a higher-order relation in the base. The systematicity principle means that a predicate that belongs to a partially mappable system of mutually constraining relations is more likely to be carried over than one which does not. It reflects a tacit preference for coherence and deductive power in analogy. Objects and their attributes can be arbitrarily different between the two domains; it is the relational structure that overlaps analogy.[4]

Literal similarity differs from analogy in that it involves overlap among both object-attributes and relations between the objects. To see this difference, let us compare two assertions:

(1) "The atom is like the solar system." (analogy)

(2) "The Dniep solar system is like our solar system." (literal similarity).

---

[4]This description does not specify how the relational mapping is achieved. In the case when the person hearing the analogy has no knowledge about the target, the learner may simply be told the object correspondences; then the intended inferences in the target can be derived simply by mapping across the default predicate structure from the base, according to the rules of analogy. However, more commonly, the learner knows something about the target domain. In this case, the object correspondences can often be derived by matching known relations in the two domains (see Falkenhainer, Forbus & Gentner, 1986). Either way, once a set of object correspondences is chosen, then further predicates from the base can be mapped, even predicates previously not known in the target domain. Thus new predictions can be generated.

Assertion (1), the analogy, conveys that the components of the two systems participate in the same relations: e.g., that the atom has a central object more massive than peripheral objects that are attracted to it and revolve about it. (See Figure 1.) It does not lead us to expect that there must also be overlap in the attributes of the objects. The nucleus of the atom need not have the same mass as the sun, any more than it need be yellow and fiery. Rather, we expect it to participate in the same relations with its peripheral objects as does the sun. In analogy, the object correspondences are determined by the roles of the objects in the relational structure, not by any intrinsic similarity between the objects themselves.

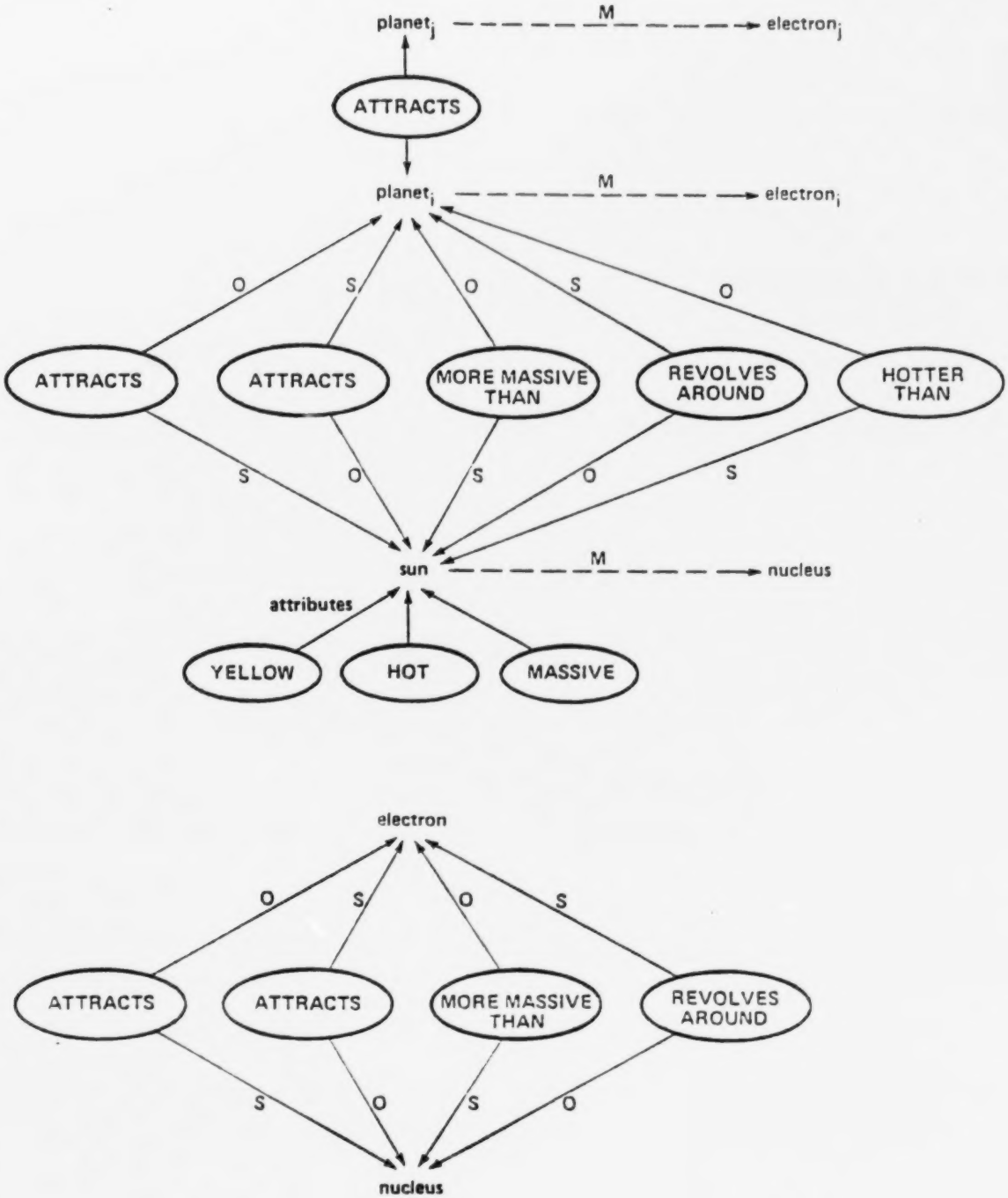
In contrast, the literal similarity statement [assertion (2)] leads us to expect not only overlap among relations but also overlap in object-attributes. We expect to find that the central star in the Dniep solar system is roughly similar to the sun in our solar system in composition, mass, size, and color, and that the number of planets will be roughly similar to our own case, and so on.

Metaphor. The structure-mapping framework can also be applied to metaphor. Many -- if not most -- of the metaphors that people consider interesting or worthwhile are analyzable as structure-mappings (Gentner, 1982; Gentner, Falkenhainer & Skorstad, 1987; also, see Miller, 1979, for a related analysis). For example, consider John Donne's comparison of two lovers to twin compasses:

> If they be two, they are two so/As stiff twin compasses are two; Thy soul, the fixed foot, makes no show/To move, but doth if the other do.
>
> And though it in the center sits,/Yet when the other far doth roam/It leans and hearkens after it,/And grows erect as that comes home.
>
> Such wilt thou be to me, who must,/Like the other foot, obliquely run;/Thy firmness makes my circle just,/And makes me end where I begun.

Figure 1

Representation of the Rutherford analogy "The atom is like the solar system."



Clearly this comparison of two lovers to twin compasses is not meant to suggest that either person possesses the attributes of a compass - they need not be long and thin, or pointed, hinged, etc. Rather, this metaphor is meant to convey a system of interconstraining relations: that the two entities are linked together such that when one entity moves visibly, the other also moves, though less obviously; that the fixed entity helps the mover stay on course; and above all that the continuous motions of the two entities are inextricably linked through mutual causality. This relational metaphor is an elegant example of structure-mapping. Similarly, in Shakespeare's comparison of Juliet to the sun, Romeo is not saying that Juliet is yellow, hot or gaseous; instead his comparison conveys that she appears above him, makes him glad, and so on. Both these metaphors convey similarity of relational structure, not of object attributes. Aside from such relational metaphors, another class of metaphors that is straightforward to analyze is mere-appearance matches, in which the base and target simply share one or two striking object-attributes. Examples are:

The sun is an orange.

The clouds were like fish scales.

But although comparisons based on one or two attributes can qualify as metaphors, they may not be considered as apt as relational metaphors (See below). Finally, there are some metaphors that are flatly not analyzable as structure-mappings: namely, those for which no clear object object correspondences can be determined. In such metaphors, the object mappings may be N--1 or 1--N mappings, or they may simply be unclear. This lack of

clarity does not necessarily impair their appeal, as in this metaphor of Byron's:

> She walks in Beauty, like the night
> Of cloudless climes and starry skies;
> And all that's best of dark and bright
> Meet in her aspect and her eyes:
> Thus mellow'd to that tender light
> Which Heaven to gaudy day denies.

In informal questioning I have found that people often like this metaphor even though they cannot say for certain which objects map with which: whether it is she, or her Beauty, or her walking in Beauty that corresponds to the night of cloudless climes and starry skies. Such metaphors may be partially analyzable within the structure-mapping framework, but they clearly violate the rule of consistency of object-correspondences.

In this paper I will consider only metaphors that can be analyzed as 1-1 mappings--i.e., the first two classes above. For these metaphors, structure-mapping predicts that (1) people should seek relational interpretations whenever possible and (2) people will consider metaphors apt to the extent that they can find relational interpretationa. As a psychological model, structure-mapping is rather elaborate. It assumes that comprehension of metaphor and analogy involves on-line processing of complex representational structures, and that the matching process is sensitive to distinctions about predicate structure. It is reasonable to ask whether such an elaborate representational account is really necessary. Other accounts of metaphors have been proposed that do not require this degree of representational structure. The most influential of these is Ortony's (1979) theory of salience imbalance.

Salience Imbalance and Metaphoricity

The central claim of Ortony's theory is that metaphoricity involves a difference in relative salience among the matching features from the base and target (Ortony, 1979). According to salience imbalance theory, what distinguishes metaphor from literal similarity is an asymmetry in the salience of the features or attributes that are shared between the base and target. In a literal similarity statement, (e.g., "Billboards are like placards.") the shared features are of high salience in both the target and the base domain. In a metaphorical comparison, such as the simile "Billboards are like warts.", the shared features (such as ugly) are of high salience in the base (warts) and of low salience in the target (billboards).

An important line of support for the salience imbalance account is the observation that metaphors tend to be strongly directional. For example, the simile "Billboards are like warts" is interpreted to mean roughly "Billboards are ugly bumps on the landscape." But reversing the order of terms produces a very different interpretation: "Warts are like billboards." is likely to be interpreted in terms of 'prominent advertising' rather than of ugliness. In contrast, reversing the base and target in a literal similarity comparison produces relatively little change in interpretation: e.g., the statements "Billboards are like placards." and "Placards are like billboards." do not differ much in interpretation. Ortony interprets this strong directionality in metaphor in terms of salience imbalance. Since the interpretation of a metaphor depends on matching high-salient features of the base (the second term) with low-salient features of the target (the first term), reversing the order of terms tends to change the interpretation.

This core observation linking directionality with salience imbalance is extremely persuasive. We might ask, then, whether salience imbalance theory could provide an account of how analogies and metaphors are interpreted. In Ortony's (1979) paper there is some ambiguity as to the strength of the claims concerning salience imbalance. The central tenant is simply that metaphors tend to display salience imbalance: that is, if the interpretation of the metaphor is laid out next to the prior representations of the two terms, it will be found that the intended commonalities are more salient in the base term than in the target term. A second, somewhat stronger possible claim is that salience imbalance is "a principal source of metaphoricity" (Ortony, 1979, p. 164): that is, it is an imbalance in salience levels that causes a comparison to be seen as metaphorical. Finally, the third and strongest possible claim is that salience imbalance is the heuristic that people use in interpreting metaphors: that is, that people scan the representation of the base, starting with high-salience features and moving on through lower-salience features, until they find a feature or a set of features that matches or is similar to a feature(s) in the target -- which, in the case of metaphors, will tend to be of low salience in the target (Ortony, 1979, p. 172).

On the first interpretation, salience imbalance is a general tendency that might come from a number of factors. On the second interpretation, degree of salience imbalance determines the degree to which we take a comparison to be metaphorical. On the third, and strongest interpretation, people use salience imbalance as part of the comprehension process: in interpreting a

metaphor people are seeking to find matches between high-salient features of the base and low-salient features of the target.[5]

In this research I am concerned with how people interpret and judge metapbor and analogy, given the prior representations of the base and target. Therefore, I will be concerned with claims II and III of the salience imbalance account. To reiterate, the strongest of these is claim III: that people use salience imbalance as an interpretation heuristic for metaphors, by seeking to find matching or similar features that are high-salient in the base and low-salient in the target. Claim II of salience imbalance, somewhat weaker, postulates that, however the feature matches are achieved, the subjective degree of metaphoricity of the match is determined by the degree of salience imbalance. By this account, salience imbalance does not constrain the matching process, but once the matching features are found, their degree of salience imbalance determines how metaphorical the comparison will seem. Thus in the succeeding pages I will be using 'salience imbalance' in the strong sense, as an interpretive theory (i.e., as including claims II and III). To anticipate the results somewhat, I found no evidence for either claim II or claim III of salience imbalance. However, claim I is compatible with the results obtained. Therefore I will suggest that salience imbalance be viewed neither as an interpretation heuristic for metaphor nor as defining of metaphoricity but rather as a general tendency resulting from pragmatic factors. This interpretation is, I believe, consistent with Ortony's chief line of theorizing (Ortony, 1979; Ortony, Vondruska, Foss & Jones, 1985).

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[5]Ortony (1979, p. 173) further speculates that if not match is found in the target for a high-salient base feature, then a new feature might be predicted in the target (attribute-introducing).

It is instructive to compare structure-mapping and salience imbalance in the ways they each differ from the contrast model of similarity proposedby Tversky (1977). Tversky models the degree of judged similarity between two items a and b as a weighted function of the common attributes of a and b, less weighted functions of the two difference sets of attributes of a not shared by b and of b not shared by a. Salience imbalance theory differs from Tversky's model primarily in that the salience of a feature is no longer an absolute measure, but is defined relative to the particular object of which it is an attribute, and to other contextual features.[6] Salience-imbalance theory explains metaphoricity in terms of the difference in relative salience of the matching features. If the matching features possess equal (and reasonably high) salience in base and target, the comparison is one of literal similarity. If the matching features are of high salience in the base and low salience in the target, the comparison is metaphorical.

Structure-mapping supplements Tversky's account in a different way, by distinguishing among kinds of predicates: attributes are distinguished from relations, and higher-order predicates from lower-order predicates. It explains metaphoricity in terms of differences in the number and the kinds of predicates that match. If substantial numbers of both relations and attributes match, the comparison is one of literal similarity. If only relational structure matches, the comparison is an analogy. A comparison is

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[6]Ortony generally uses the term "attribute" where Tversky used "feature." It is important to note that neither term should be taken to refer only to one-place predicates. Rather, both accounts are neutral as to predicate kind and predicate structure. Thus, Ortony's term "attributes" includes what I have called attributes, relations, and higher-order relations, without distinguishing among them.

metaphorical to the extent that there are few matching predicates, anda metaphorical comparison is apt to the extent that it is analogical: i.e., to the extent that its matching predicates are primarily relational predicates.

Structure-mapping and salience imbalance make different predictions concerning the relation between metaphor interpretation and prior knowledge of the base and target domains. In order to compare the two theories, subjects were asked to write out descriptions of objects that, unbeknownst to them, would later appear in metaphors. Then they were asked to write out interpretations of the metaphors, in either forward or reversed order. In addition, they rated the metaphors for metaphoricity and aptness. In an effort to ensure fairness to the salience imbalance position, the metaphors were taken from the set of examples that Ortony (1979) had used to illustrate the theory.

The structure-mapping hypothesis states that people prefer interpretations of metaphors that preserve relations from the base and drop object-attributes. This generates three specific predictions. First, the metaphor interpretations will contain relatively more relations (as opposed to attributes) than the object descriptions. This means that the difference between relationality and attributionality ratings will be greater for the metaphor interpretations than for the object descriptions. Second, the metaphor interpretations will include relational information rather than object attributes: that is, the relationality ratings will be greater than the attributionality ratings for metaphor interpretations. The third and most important prediction concerns the aptness ratings. The more relations subjects can map from base to target, the more apt they will find the metaphor. Therefore, the aptness ratings for metaphors should be positively correlated with the relationality of the metaphor interpretation. No such

prediction holds for attributes: there should be either no correlation or a negative correlation between aptness rating of a metaphor and the attributionality of its interpretation.

The salience imbalance theory makes three predictions. First, since perceived metaphoricity depends on salience imbalance, the rated metaphoricity of forward metaphors should be greater than that of reverse metaphors. Second, the chief determinant of which aspects of the object descriptions are used in the metaphors should be salience imbalance. Using order-of-mention as a measure of salience, this means that the metaphor interpretations should contain a preponderance of features that are mentioned early in the base description and late, if at all, in the target description. Third, if the metaphors vary in the degree to which they display salience imbalance, the rated metaphoricity should depend on the degree of salience imbalance.

Experiment 1

To compare structure-mapping with salience imbalance, interpretations of metaphors were collected and analyzed and compared with subjects' descriptions of the individual objects used as base and target. The experimental manipulations were (1) object description versus metaphor interpretation; and (2) forward versus reversed metaphor. The dependent variables were the subjects' ratings of aptness and metaphoricity, as well as certain measures specific to the theories being tested. In order to test the structure-mapping predictions, a measure of the attributionality and relationality of propositions was required. Two different independent assessments of attributionality and relationality are described below. In order to test the salience imbalance predictions, a measure of the relative

salience of each proposition in the object descriptions was required. For this, the order of mention of propositions was used.

Method

Subjects. Twenty undergraduate college students (two groups of ten each) from the Cambridge, Massachusetts area, served in the basic metaphor interpretation task. They were paid for their participation. Two other groups served as judges in the scoring tasks (Phase 2): (1) five advanced undergraduate psychology students at the University of California at San Diego, who received course credit for their participation; and (2) twenty-two undergraduate students (two groups of eleven each), also from U.C.S.D., who received course credit for participating.

Materials. Eight metaphors[7] were taken from Ortony's (1979) paper. Table 1 shows the list of comparisons, in forward order. There were two sets of metaphor stimuli, each containing four metaphors in forward order (e.g., "Sermons are like sleeping pills.") and four in reversed order (e.g., "Gold mines are like encyclopedias."). Each set also contained eight filler metaphors, always in forward order, for a total of sixteen metaphors. There were two groups of subjects, so that forward-reverse presentation of the metaphors was counterbalanced, and no subject received forward and reverse versions of the same metaphor.

In the object-description part of the task, subjects had to describe each object term mentioned in the metaphors. There were 16 terms for the experimental metaphors and 16 for the filler metaphors, for a total of 32 terms. These were presented in random order.

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[7]Most of the examples are actually similes; but, as Ortony has argued convincingly, psychologically the metaphor-simile difference is primarily a surface distinction.

Table 1

Materials Used in Experiment 1

Blood vessels are like aqueducts.

Surgeons are like butchers.

Education is like a stairway.

Sermons are like sleeping pills.

Cigarettes are like time bombs.

Science is like a Glacier.

Encyclopedias are gold mines.

Billboards are like warts.

Procedure: Phase 1. Subjects were run in two groups of ten people, differing only in which metaphors were forward and which were reversed. The first task was the object-descriptions task. Subjects were told to write out a description for each of the individual terms - e.g., sermons, sleeping pills. The 32 object terms were presented in workbooks, each term on a separate page. They were randomly ordered, except that the two terms from a metaphor were never presented contiguously.

After the object descriptions were completed, the subjects were told that they were to interpret metaphors. The 16 metaphors were presented in workbooks, in random order, one to a page. Subjects were told to write out their interpretation of each metaphor --- i.e., to write its intended meaning, what the author seemed to be trying to convey. They also rated the metaphoricity and aptness of each metaphor on separate 1-5 scales. They were told that metaphoricity had to do with whether the comparison was literal or nonliteral, and aptness with how clever, interesting, and worthwhile the comparison was.

Procedure: Phase 2: Scoring. To test the structure-mapping hypothesis, the relationality and attributionality of the responses were rated in two ways: (1) by a small, trained group of advanced undergraduates (Trained Judges' Ratings); and (2) by a group of 22 undergraduate subjects with no special training (Undergraduate A/R Ratings). To test the sal-imb hypothesis, two of the trained judges rated whether the propositions that occurred in the metaphor interpretations occurred early or late (if at all) in the object descriptions (Salience Ratings).

Trained Judges' Ratings of Relationality and Attributionality. Five advanced undergraduate psychology students from U.C.S.D. served as judges. All had some advanced training in linguistics or psycholinguistics. In

addition, they received roughly ten hours of training in the use of propositional notation to represent meaning. They were unaware of the particular hypotheses of the study, and were not told the aptness rating or metaphoricity rating, nor the forward-reverse condition of the original metaphors.

Three to five judges participated in each scoring session. All 20 responses for a given metaphor (10 from the forward presentation and 10 from the reversed) were rated in one session. These 20 interpretations were read in random order. Each judge rated the entire interpretation as to its relationality and attributionality, each on a 1-5 scale. Relationality was defined as the degree to which the predicates in the response expressed relations, either between objects in the domain or between relations. Attributionality was defined as the degree to which its predicates described objects in and of themselves, independently of the domain. There was no discussion during this phase, except that the interpretations were reread as many times as necessary until the judges had all arrived at their private ratings. These ratings were recorded by the scribe (who also served as reader). After the judges had read out their ratings, disagreements were resolved by discussion and a final rating was agreed on. The agreement among the first set of ratings, before discussion, was .91. Immediately after rating the metaphor interpretation, the judges rated the relationality and attributionality of the object descriptions for the same metaphor (20 descriptions of each of the two objects). These were rated in the same way as the metaphor interpretations. They were read to the judges in a different random order from the metaphors.

Attributionality and relationality are judgements about the conceptual predicate structure underlying the surface language. In most cases, the

form of the surface expression makes it clear whether the underlying predicate is an attribute or a relation. Predicates that take two or more objects, such as transitive verbs, were scored as expressing relationships between their arguments, e.g., "X hit Y"; "X likes Y". Adjectives often express single-object attributes; e.g., "X is cold"; "X is red"; "X is tall". However, when an object attribute was stated as a non-adjectival proposition; e.g., "X is ten feet tall", or "X's height is ten feet" - the proposition was classified as an object attribute. Comparatives were treated as relations. For example, a comparison involving size ("X is larger than Y," or "X is four kilograms greater in mass than Y.") is a 2-place predicate expressing a relation between attributes of objects. These were scored as first-order relations, on the same level as a relation between objects.

For the cases discussed so far, there are clear surface signs of their relational or attributional usage - e.g., comparative inflections, presence of more than one noun argument - so they do not pose a serious classification problem. A more difficult set of cases arises when underlying relations are expressed as surface attributes, through a process of abstraction (see Miller, 1979). For example, the adjective soporific, in "X is soporific." is stated as though it were a quality of X, but in fact conveys relational information: that there exist beings whom X puts to sleep. It stands for a set of relational statements like "X puts Y to sleep.", "X puts Z to sleep.", etc. These kinds of terms are both relational, in their underlying meaning, and attributional, in that the person has chosen to express the quality as an attribute. In our studies, such abstracted relational adjectives were scored as conveying both relational and attributional meaning, in moderate degree.

Undergraduate A/R Ratings. A second method of scoring for relationality and attributionality was also used. This method differed from the previous rating method in three ways: (1) groups of untrained subjects were used, rather than trained judges; (2) each response was broken into individual propositions, rather than being rated as a whole, and (3) one combined rating scale was used, rather than separate scales for attributionality and relationality.

The raters were 22 undergraduate subjects with no special training. They were divided into two groups, corresponding to the two groups of original subjects. The metaphor interpretations were broken into individual propositions, which were presented in random order, within and across metaphors. Only propositions from the metaphor interpretations were rated; the object descriptions were not included in this task. Each group of eleven raters scored all propositions generated by one of the original groups of ten subjects. They were told to rate each proposition on a composite scale, ranging from 1 = highly attributional to 5 = highly relational. Examples of highly attributional statements were "X is red," and "X is large." Examples of highly relational statements were "X puts people to sleep," and "X causes explosions."

Scoring for Salience Imbalance. To test the salience imbalance theory, two of the advanced undergraduates described above compared the metaphor interpretations with the object descriptions for propositional overlap. They were unaware of the hypothesis being tested, and of the original subjects' aptness and metaphoricity ratings. Forward or reversed metaphors were scored separately; however, the judges were not told the significance of this variation. For each metaphor, they were told to compare subjects' interpretations of the metaphor with their descriptions of the base and the

target objects, to see whether any of the same propositions occurred. They were told that "same propositions" should be taken as statements with the same meaning, not necessarily stated identically. When a proposition from the metaphor interpretation was found in one of the descriptions, it was scored as to whether it also occurred in the base and/or target description; and if so, whether it occurred in the first half of the description or the second half of the description. The outcome of this scoring procedure was, for each metaphor, the number of propositions that the original subject had included both in the metaphor interpretation and in (a) the base; (b) the target; (c) the top half of the base; (d) the bottom half of the base; (e) the top half of the target; (f) the bottom half of the target.

Results and Discussion

Structure-mapping. The results support the structure-mapping hypothesis. The first two predictions of the structure-mapping theory are (1) that the metaphor interpretations would contain relatively more relational information than would the object descriptions, and (2) that the metaphor interpretations would contain more relational information than attributional information. Table 2 shows a typical response. Both relations and object attributes appear in the object descriptions, but only relational information appears in the metaphor interpretation. A comparison of the Trained Judges' ratings of metaphor interpretations and object descriptions bear out these predictions. The mean relationality ratings were 4.9 for the object descriptions and 4.8 for the metaphor interpretations. The mean attributionality ratings were 4.3 for the object descriptions and 2.4 for the metaphor interpretations. Thus, the object descriptions were both highly relational and highly attributional; the

Table 2

Sample Response in Experiment 1:

Object Descriptions and Metaphor Interpretation

Cigarettes are like Time Bombs

	Response	Trained Judges' Ratings	
		Rel.	Att.
Base:	time bomb		
	Explosive devices with detonator linked to timing device	5	5
	Explosion time can be pre-set		
	Perpetrator doesn't have to be present		
Target:	cigarette		
	Chopped cured tobacco in paper roll	5	5
	With or without a filter at the end held in the mouth		
	With or without menthol		
	Lit with a match and breathed through to draw smoke into the lungs		
	Found widely among humans		
	Known by some cultures to be damaging to the lungs		
	Once considered beneficial to health		
Metaphor:	Cigarettes are like time bombs		
	They do their damage after some period of time during which no damage may be evident	5	1

Aptness: 3

Metaphoricity: 5

metaphor interpretations were highly relational but not highly attributional.

An analysis of variance was performed for the within-subjects factors of Directionality (forward vs. reverse), Task (metaphor vs. object), and Measure (relationality vs. attributionality). For our purposes, the chief interest is in the interactions, particularly in the predicted interaction between Task and Measure. However, let us first consider main effects. There was a main effect of Task, reflecting the overall higher ratings for the objects than for the metaphors, $F(1,19) = 262.44$, $p < .001$. The mean rating (averaging across relationality and attributionality ratings) was 4.6 for objects and 3.6 for metaphors. Measure was also significant as a main effect, indicating that overall the responses were judged as higher in relationality (with a mean of 4.8) than in attributionality (with a mean of 3.3) $F(1,19) = 419.08$, $p < .001$. The reflects the fact that only the object descriptions tended to be high in attributionality, while both kinds of responses were high in relationality. There was no main effect of Direction, $F(1,19) = 3.20$, NS

The key prediction was confirmed: there was a significant interaction of Task and Measure, reflecting the fact that the mean attributionality rating drops sharply from object descriptions to metaphors, while the mean relationality rating changes very little, $F(1,19) = 129.94$, $p < .001$. Planned comparisons revealed that both attributionality and relationality differed significantly between metaphors and objects $t(39) = 18.01$, $p < .001$; $t(39) = 2.05$, $p < .05$, respectively. Finally, there was also a significant interaction between Direction and Task $F(1,19) = 11.30$, $p < .01$. Not surprisingly, direction affected metaphors but not objects: the mean average rating of relationality-attributionality was 3.7 for forward

metaphors and 3.4 for reverse metaphors; the mean rating was 4.6 for objects, regardless of the direction of the subsequent metaphor.

An items analysis revealed the same patterns of significance as the subjects analysis, except that the interaction between Direction and Task was nonsignificant in the items analysis. There were main effects of Task and Measure, $F(1,7) = 66.15$, $p < .001$ and $F(1,7) = 21.68$, $p < .001$, respectively. The key interaction of Task and Measure was also significant $F(1,7) = 15.10$, $p < .01$.

As noted above, the Trained Judges' mean relationality rating (4.8) was higher than the mean attributionality rating (2.4) for metaphors, $t(15) = 6.68$, $p < .0005$, one-tailed. This difference holds up for individual metaphors. The Trained Judges' mean relationality rating was higher than the mean attributionality rating for every one of the eighteen metaphors (counting both forward and reverse versions).

The third and most important prediction of the structure-mapping theory is that aptness should be positively correlated with relationality in metaphor interpretations. That is, subjects should consider those metaphors most apt for which they have found the most relational interpretations. The prediction is specific to relationality: there should be no correlation, or even a negative correlation, between aptness and attributionality. This prediction was confirmed using both the Trained Judges' ratings and the Undergraduate A/R ratings.

Pearson's product-moment correlations were performed on the mean ratings for the 16 metaphors. Table 3 shows the correlations among the mean original aptness ratings, the trained judges' ratings of relationality and attributionality, and the undergraduates' attributionality-relationality ratings. For completeness, the metaphoricity correlations are also shown.

Table 3

Results of Experiment 1: Correlations Between The Original Subjects' Ratings of the Metaphors and Judges' Ratings of their Responses

Judges' Ratings	Original Subject's Ratings	
Metaphors Interpretations	Aptness	Metaphoricity
Relationality (Trained Judges)	r = .65**	-.08 NS
Attributionality (Trained Judges)	-.31 NS	.43 NS
A/R Rating (Group Raters)	.56*	-.45 NS
Object Description		
Relationality of Base & Target	-.28 NS	-.30 NS
Attributionality of Base & Target	-.25 NS	.62*

As predicted, aptness is positively correlated with the trained judges' ratings of relationality, $r = .65$, $p < .01$. There is a nonsignificant negative trend in the correlation between aptness and attributionality, $r = -.31$, NS. Finally, as a confirming measure, aptness correlates positively with the undergraduate A/R rating, $r = .56$, $p < .05$. Since the A/R rating is high for relational statements and low for attributional statements, this positive correlation again confirms the connection between relationality and aptness. This suggests that subjects judged the aptness of a metaphor by the degree to which it could support a relational interpretation.

Finally, as a check on the reliability of the measures, correlations were performed between the Trained Judges' mean ratings of relationality and attributionality and the undergraduate A/R ratings for metaphors. If the measures agree, the correlation should be positive for relationality and negative for attributionality. Indeed, the measures are consistent. The correlation with A/R rating is .62 for relationality and -.65 for attributionality $r(14) = .62$, $p < .05$ and $r(14) = -.65$, $p < .01$, respectively.

Salience Imbalance. The results are not positive for salience imbalance. According to the salience imbalance hypothesis, metaphoricity arises chiefly from an asymmetry in the salience of the matching features: a comparison should be more metaphoric to the degree that the matching features are of high salience in the base and of low salience in the target.

Prediction 1. The first prediction is that metaphoricity ratings should be higher for forward metaphors than for reversed metaphors. This is because the feature matches for the forward metaphors --- e.g., "Cigarettes are like time bombs." --- should have satisfied salience imbalance to a

greater degree than should the reversed metaphors --- e.g., "Time bombs are like cigarettes."

This prediction was not confirmed. Table 4 shows the mean aptness and metaphoricity ratings, we well as the ratings of relationality and attributionality, for forward versus reversed metaphors. The mean metaphoricity, as rated by the original subjects, was 3.8 for forward metaphors and 3.6 for reversed metaphors, $t(7) = 1.21$, NS. Thus the first prediction of the salience imbalance theory is disconfirmed. Although the forward and reversed metaphors appear to differ more in aptness than in metaphoricity, the aptness difference is also nonsignificant: the mean original aptness rating is 3.3 for forward and 2.7 for reversed, $t(7) = 1.77$, NS. The only significant difference between forward and reversed metaphors is in relationality. The trained judges' rating of relationality are 4.9 for forward and 4.6 for reversed metaphors, $t(7) = 2.51$, $p < .05$. There were no significant differences between forward and reversed metaphors in attributionality, nor in undergraduate A/R ratings. Thus, to the extent that forward and reversed metaphors show any significant difference, it is in the relationality of their interpretations. This difference in relationality suggests, perhaps, that some asymmetric processes occur in metaphor comprehension. However, there is no evidence that these asymmetries involve differences in metaphoricity.

Prediction 2. The second prediction of Ortony's salience imbalance theory is that the metaphor interpretations should primarily include propositions that are of high salience in the base and of low salience in the target. To evaluate this prediction, the measure of salience used was the order of mention in the object descriptions. Thus, the prediction is that the metaphor interpretations should tend to include propositions

Table 4

Results of Experiment 1:

Comparison of Forward and Reversed Metaphors

	Original Ratings		Characteristics of Interpretations		
	Aptness	Metaphoricity	Relationality [a] (Trained Judges)	Attributionality (Trained Judges)	A/R Rating (Group Raters)
Forward Metaphors	3.31	3.80	4.91	2.51	3.10
Reversed Metaphors	2.70	3.60	4.60	2.24	2.99

Note:

a. The only significant difference between the forward and reversed conditions is in relationality [$t(7)=2.51$, $p < .05$, one-tailed].

mentioned early in the description of the base object and late in the description of the target object. In order to give the hypothesis every possible opportunity, a series of predictions was tested, beginning with the strongest prediction and testing progressively weaker variants. Figure 2 shows a schematic depiction of the predictions and Table 5 shows the results.

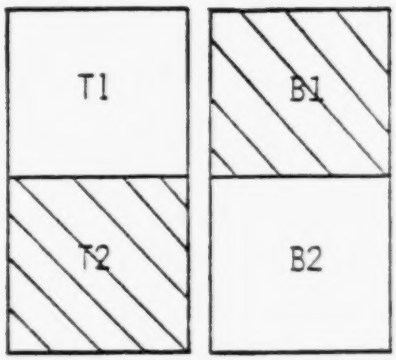
The most straightforward prediction is that there should be more metaphor assertions from the top-half-of-base and bottom-half-of-target than from the reverse intersection, the bottom half of base and top-half-of-target (See Figure 2). That is, the metaphor interpretations should contain primarily information that is high-salient in the base and low-salient in the target. This prediction is not confirmed: the mean numbers of propositions in the two intersections are .038 and .025, respectively, $\underline{t}(15) = .81$, NS.

But perhaps the halfway point is the wrong cutoff for high versus low saliency. Perhaps all or most of the information subjects mentioned in their object descriptions was of high salience to them. In that case the prediction should simply be that the metaphors will contain more propositions from the base description than from the target description. This too is disconfirmed. The mean number of propositions from the metaphor interpretation that also appear in the object description is 1.16 for the base and 1.04 for the target, $\underline{t}(15) = .51$, NS. (For comparison, the mean number of propositions per metaphor interpretation is 4.66.)

The two most straightforward versions of the salience-imbalance prediction have been tested and disconfirmed. However, there are four weaker versions of the prediction that can be tested. First, within the base, salience imbalance could predict that that metaphor interpretations

Figure 2

Schematic depiction of interpretation predictions derived from salience imbalance theory.



TARGET BASE

e.g. sleeping pills e.g. sermons

"A T IS LIKE A B"

e.g. Sermons are like sleeping pills

Table 5

Results of Experiment 1: Mean Numbers of Predicates Occurring in Metaphor Interpretations

Predictions of Salience Imbalance	Results: Mean Number of Predicates[a]		
B1 ∩ T2 > B2 ∩ T1	B1 ∩ T2 = .038	B2 ∩ T1 = .025	NS
B > T	B = 1.16	T = 1.04	NS
B1 > B2	B1 = .58	B2 = .58	NS
T2 > T1	T2 = .49	T1 = .56	NS
B1 > T1	B1 = .58	T1 = .56	NS
T2 > B2	T2 = .49	B2 = .58	NS

[a] Notation: All abbreviations refer to mean number of predicates occurring in a subject's metaphor interpretation that appear also in specified parts of S's object descriptions.

B = N in base description

T = N in target description

B1 = N in top half of base description

B2 = N in bottom half of base description

T1 = N in top half of target description

T2 = N in bottom half of target description

B1 ∩ T2 = N in both top half of base and bottom half of target descriptions

should contain more propositions from the top half of the base than from the bottom half of the base. In fact, the numbers are identical: the mean number of propositions in the metaphor interpretations from the top half of the base is .58, identical to the number from the bottom half of the base. The second additional test concerns the corresponding prediction for the target description: there should be more propositions from the bottom half (the less salient portion) of the target description than from the top half. This prediction too is invalidated: a mean of .49 assertions from the bottom and .56 from the top of the target was found. This (nonsignificant) difference is in the opposite direction to the prediction, $\underline{t}(15) = .54$, NS.

The third possible variant of the salience-imbalance prediction is that more of the metaphor propositions should come from the top half of the base than from the top half of the target. This prediction is disconfirmed: the mean number of metaphor propositions is .58 from the top half of the base and .56 from the top half of the target, $\underline{t}(15) = .17$, NS. Finally, a similar prediction is that more of the metaphor propositions should come from the bottom half of the target than from the bottom half of the base. This too is disconfirmed: the means are .49 and .58, respectively, a nonsignificant difference in the wrong direction, $\underline{t}(15) = .73$, NS.

Overall, the second major prediction of the salience imbalance hypothesis is not supported here. Not one of the six possible versions of this prediction is borne out. There is no evidence that salience imbalance determines the information people use in their metaphor interpretations.

However, there is still one more way in which effects of salience imbalance could show up. Even though salience imbalance did not hold for the metaphors overall, if salience imbalance is the key to metaphoricity, we

should find that the metaphors that best display salience imbalance are considered the most metaphorical.

Prediction 3. This brings us to the third prediction of the salience imbalance hypothesis: that metaphoricity should be correlated with the degree of salience imbalance in the metaphors. This means that metaphoricity should be positively correlated with the proportion of interpretation statements from the base and negatively correlated with the proportion of interpretation statements from the target that enter into the metaphor interpretations.

Instead, we find that metaphoricity is negatively correlated both with the number of statements from the target, $r(14) = -.69$, $p < .01$ and with the number of propositions from the base $r\ (14) = -.56$, $p < .05$. Since this is a key prediction for the salience imbalance theory, it seemed advisable to check whether it held for the forward metaphors only. However, here the results are slightly worse for the theory: the correlation between metaphoricity and number of statements from the base, which should be positive, is still more strongly negative $r(6) = -.65$, NS.

As a final effort, it seemed worth testing whether this prediction might apply to aptness rather than to metaphoricity. That is, perhaps there is something right about the salience imbalance intuition, but the intuition really applies to aptness rather than to metaphoricity. In this case, aptness should be positively correlated with the number of propositions from the base description and negatively correlated with the number from the target description that enter into the metaphor interpretation. This possibility, too, was disconfirmed. The correlations between aptness and number of object propositions are nonsignificant both for the base and for the target descriptions $r(14) = .28$ and $r(14) = .05$, respectively.

Discussion

The results provide no support for Ortony's claim that salience imbalance is a principal source of metaphoricity. Neither aspect of this claim accords with the results: no difference in metaphoricity was found between the forward and reversed metaphors; and no evidence for salience imbalance was found in comparing the object descriptions with the metaphor interpretations. Nor can this lack of positive evidence be plausibly attributed to an inappropriate choice of stimuli, since the metaphors used were those offered as illustrations of salience imbalance theory in Ortony (1979). Overall, these results give us no reason to assume that salience imbalance has a special role in metaphor interpretation.[8]

These results provide considerable support for the structure-mapping view. These results suggest that when people interpret metaphorical comparisons, they adopt a (possibly unconscious) set of assumptions concerning which aspects of their object representations are relevant. They tacitly assume that relational information, rather than information about object-attributes, is meant to be preserved in the analogical mapping. The three predictions of the theory were verified. First, although subjects' descriptions of the base and target objects are high in both relational and

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[8]Of course, it should be noted that the negative findings on predictions (2) and (3) might be challengable. Testing these predictions required comparing high-salient and low-salient aspects of the object descriptions with the metaphor interpretations. The theory does not specify how best to estimate salience. The assumption made here is that the rough order of mention of information in a person's description of a term (i.e., early or late in the description) is a fair reflection of the salience of the information for that term.

attributional information, only the relations are preserved in the analogical interpretations. The aptness correlations provide further support: the more relations people can find to map from the base to the target, the more apt they find the metaphor.

Experiment 2

The next study was undertaken to test developmental implications of the structure-mapping theory and to replicate the adult results. Here I focus chiefly on the adult data, with the child study as background. It is well-established that the ability to interpret metaphors appropriately increases with age over the years from two or three until adolescence (Dent, 1984; Gardner, Kircher, Winner & Perkins, 1975; Reynolds & Ortony, 1980; Winner, 1980). According to the structure-mapping theory, the most important component of metaphoric ability is the capability to perform relational mappings. This leads to the developmental prediction that underlying the increase in metaphorical ability should be an increase in propensity to make relational interpretations. Therefore, metaphor interpretations should become more relational with age, but not more attributional. In addition to testing the developmental predictions of structure-mapping theory, this study provides a replication of the adult patterns in Experiment 1, across different kinds of metaphors. Both the structure-mapping predictions and the salience imbalance predictions were tested with the adult subjects. Thus, this study has two purposes: (1) the developmental results test whether the structure-mapping theory can account for the increase in metaphoric ability; and (2) the adult results serve as a replication of Experiment 1. Because our interest here is in the adult patterns, the developmental methodology and results will be omitted here. See Gentner and Stuart (1984) or Gentner (1986b) for a description.

In Experiment 2, Patricia Stuart and I collected interpretations of metaphors by children and adults, as well as aptness ratings of the metaphors. As in Experiment 1, the interpretations were then scored by independent judges for relationality and attributionality. There were three metaphor types: attributional metaphors, relational metaphors, and double metaphors. In Attribute metaphors, the predicates shared by the base and target objects were object-attributes: e.g., "Pancakes are nickels." (Both are round.) In Relation metaphors, the shared predicates were relations: e.g., "A tire is a shoe." (Both are used by moving figures as points of contact with the ground.) In Double metaphors, both attributes and relations were shared: e.g., "Plant stems are like drinking straws." (Both are long and cylindrical; both are used to bring liquids from below to nourish a living thing.)

Predictions of Structure-mapping. Let us first review the predictions for adults. The structure-mapping theory makes four predictions. First, the metaphor interpretations should be higher in relationality than in attributionality. (This prediction applies only to the relational and double metaphors, since the attribute metaphors do not permit a relational interpretation.) Second, the aptness ratings should be positively correlated with the relationality of the metaphor interpretations. Third, the double metaphors, which can support either an attributional or a relational interpretation, should be interpreted relationally. Fourth, the aptness ratings should be lower for attribute metaphors than for relational and double metaphors.

One other set of predictions concerns the materials. Crucial to this theory is the claim that the distinction between attributionality and relationality can be made reasonably clearly, at least in the majority of

cases. If construction of attributional, relational and double metaphors provides a test of the orderliness of the distinction, the relationality ratings should be highest for the relational metaphors and lowest for the attributional metaphors. The attributionality ratings should show the reverse pattern.

Predictions of Salience Imbalance. The central tenet of Ortony's (1979) theory is that metaphoricity depends on salience imbalance. Thus the predictions for adults are that (1) the metaphors' interpretations should tend to include propositions mentioned early in the description of the base object and late (if at all) in the description of the target object; (2) to the extent that there is variation in the degree of salience imbalance shown in metaphor interpretations, the metaphoricity ratings should correlate positively with the degree of salience imbalance.

Method

Subjects. The adult subjects were ten college students from psychology classes at the University of California at San Diego.

Stimuli. There were eight instances each of three types of metaphor: (1) attribute metaphors, in which base and target shared many attributes but few relations; (2) relation metaphors, in which base and target shared many relations but few attributes; and (3) double metaphors, in which base and target shared both relations and attributes. Examples of the three kinds of metaphors are:

Attribute: The sun is like an orange. (Both are round and orange.)

Relational: A camera is like a tape recorder. (Both record events to re-experience at a later time.)

Double: A hummingbird is like a helicopter. (Both have stubby shapes and blurry parts; both use rapid motion to achieve maneuverability in air.

There were twenty-four comparisons in all, as shown in Table 6. All subjects interpreted all the metaphors.

Procedure. The methodology for adults was the same as for Experiment 1. The task was administered to the adults in written form, in groups. They first wrote out descriptions of the 48 separate objects (presented in random order) that later appeared in the metaphors. Then they wrote out their interpretations of the metaphors and also rated their aptness and metaphoricity.

Scoring. The metaphor interpretations were scored as in Experiment 1. The same trained judges met in groups of from two to four people and rated the responses. As before, there were two five-point scales, a relational scale and an attributional scale. The rules for propositional analysis were as described in Experiment 1. It is worth noting that this method minimizes the effect of differences in length of responses, a desirable feature in a developmental study. An interpretation received a 5 rating on relationality/attributionality if it included any clearly relational/attributional statement. This method is sensitive to the presence or absence of relational (or attributional) information in a given interpretation, and relatively insensitive to the number of different relations (or attributes) mentioned in an interpretation.

Table 6

Materials Used in Experiment 2

RELATIONAL METAPHORS

The moon is like a lightbulb.
A camera is like a tape-recorder.
A ladder is like a hill.
A cloud is like a sponge.
A roof is like a hat.
Treebark is like skin.
A tire is like a shoe.
A window is like an eye.

ATTRIBUTIVE METAPHORS

Jellybeans are like balloons.
A cloud is like a marshmallow.
A football is like an egg.
The sun is like an orange.
A snake is like a hose.
Soap suds are like whipped cream.
Pancakes are like nickels.
A tiger is like a zebra.

DOUBLE METAPHORS

A doctor is like a repairman.
A kite is like a bird.
The sky is like the ocean.
A hummingbird is like a helicopter.
Plant stems are like drinking straws.
A lake is like a mirror.
Grass is like hair.
Stars are like diamonds.

During scoring, the metaphor interpretations were read in random order, so that the judges did not know the ages of the subjects. They were not told the aptness rating or metaphoricity rating of the original metaphors. Only one of the judges knew the design of the experiment. Inter-rater agreement ranged from 85% to 100% on different metaphors.

Results

Structure-mapping. This study tested the structure-mapping theory in three ways: (1) as a test of developmental predictions; (2) as a replication of the adult patterns found in Experiment 1; and (3) as a test of the orderliness of the attributionality-relationality distinction as realized in the design of the materials. All three lines of prediction received clear support. In this paper, I focus on the adult responses. The developmental results are reported in Gentner (1986b) and Gentner & Stuart (1984).

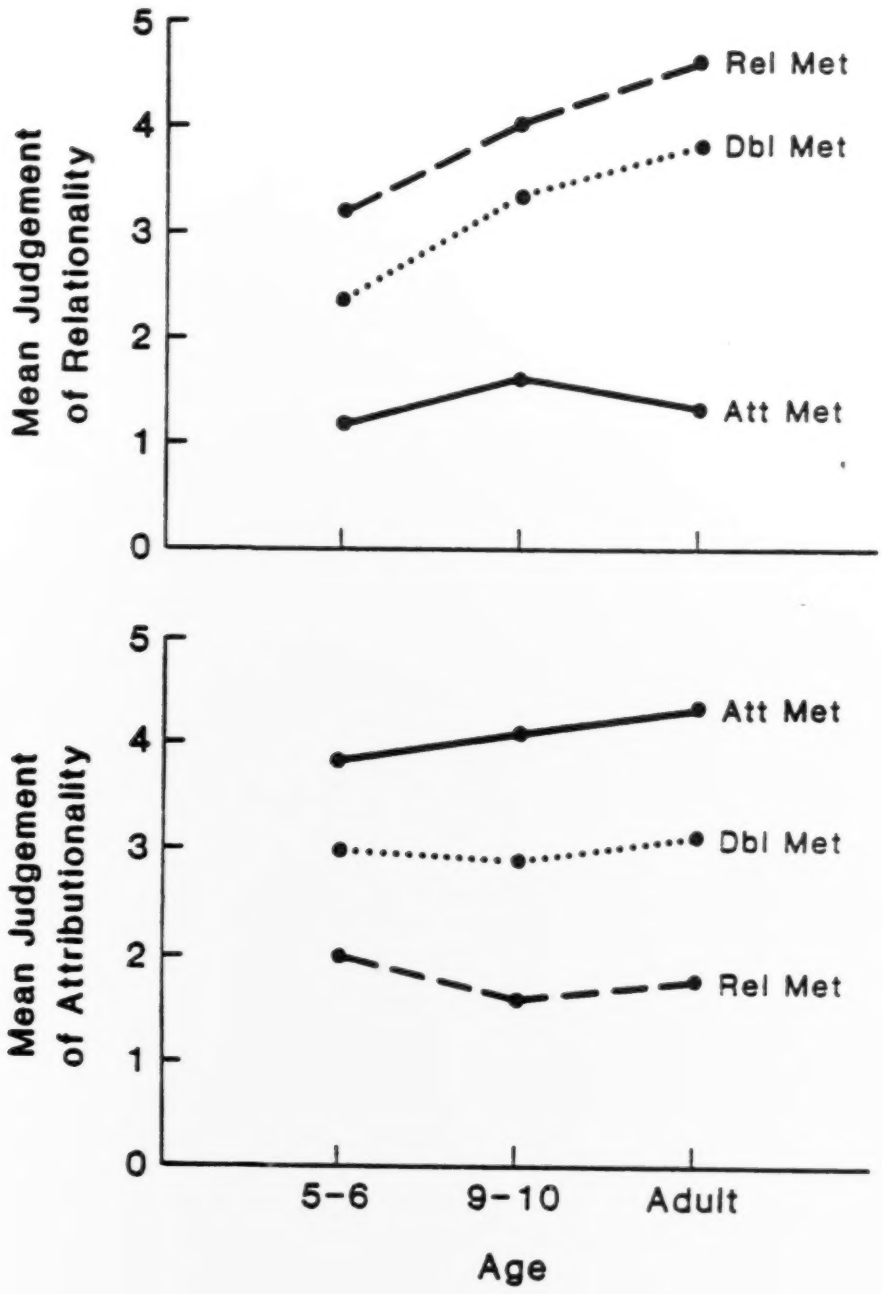
Figure 3a shows the rated relationality of the interpretations for the three types of metaphor across age. Relationality increases steadily with age for the metaphors that permit relational interpretation--i.e., the relational and double metaphors. Attribute metaphors, of course, show no such increase, since the base and target do not share relational information.

In contrast, there is no developmental increase in propensity to use attributional information. As Figure 3b shows, within each class of metaphor, the attributionality ratings are constant across age.

Two separate two-way, 3 (Age) X 3 (Metaphor type) analyses of variance were performed: one for the relationality ratings and one for the attributionality ratings. In the relationality analysis, both the main effect of Age and the Age X Metaphor-type interaction were

Figure 3

Results of Experiment 2: Mean ratings of a) relationality and b) attributionality of metaphor interpretations.



significant, $F(2,27) = 12.76$, $p < .01$ $F(4,54) = 5.48$, $p < .01$. This Age effect confirms a strong developmental trend in the use of relations in metaphorical interpretation. The Age X Metaphor-type interaction reflects the fact that, as expected, the age increase in relationality occurs only for the relational and double metaphors.

On the attributionality analysis, there was no significant main effect of Age; nor was the Age X Metaphor-type interaction significant. There is no developmental trend in propensity to produce attributional interpretations of metaphors.

As in Experiment 1, the aptness ratings for adult subjects were positively correlated with relationality, $r(22) = .55$, $p < .01$, but not with attributionality. Indeed, the adult aptness ratings were negatively correlated with attributionality, $r(22) = -.42$, $p < .05$.

Another indication that relationality figures heavily in adult aptness judgments is that adults' mean aptness ratings for double and relational metaphors are considerably higher than for attribute metaphors, $t(7) = 2.8$, $p < .05$. Again, as Table 7 shows, children do not show this pattern: their mean aptness ratings do not differ significantly across the three types of metaphors.

Materials. In both the relational and attributional analyses, the main effect of Metaphor type was strongly significant, $F(2,54) = 191.63$, $p < .001$; $F(2,54) = 265.06$, $p < .001$ respectively. For all ages, the relational comparisons received the highest relational ratings and the attributional comparisons received the highest attributional ratings. The double comparisons are intermediate on both rating scales. Thus, the results agree well with a priori categorization of stimuli. The items analysis agreed fairly closely with the subjects analysis. The relationality analysis by

Table 7

Results of Experiment 2:

Mean Aptness Ratings for Different Kinds of

Metaphors Across Age Groups

	Attribute Metaphors	Double Metaphors	Relational Metaphors
5-6	2.26	2.14	2.08
9-10	2.19	2.18	1.99
Adult	2.30	2.95	2.86

items showed the same pattern as the subject analysis, except that age is nonsignificant in the items analysis. Metaphor-type and the key interaction of metaphor-type and age are significant, $F(2,21) = 32.15$, $p < .01$ and $F(4,42) = 4.96$, $p < .01$, respectively. The attributionality analysis shows a pattern identical to the corresponding subjects analysis: only metaphor-type is significant, $F(2,21) = 24.08$, $p < .01$.

The performance on double metaphors is of special interest. By design, the double metaphors could support either an attributional or a relational interpretation. To see which kind of propositions subjects focused on in double metaphors, planned comparisons were performed within each age group between the relationality ratings and the attributionality ratings of the double metaphors. As can be seen in Figure 3, for the two older age-groups, the mean relationality for the double metaphors is greater than the mean attributionality, $t(9) = 2.78$, $p < .05$ (for 9-10-year-olds, $t(9) = 3.79$, $p < .05$ for adults. Thus for adults and older children, there is a clear preference for relational interpretations of metahors.

Salience-imbalance. Ortony's salience imbalance theory can be tested for the adults. The first prediction of salience-imbalance is that the metaphor interpretations should tend to include propositions mentioned early in the description of the base and late in the description of the target. This result is not confirmed; indeed, the results are remarkably similar to the negative results of Experiment 1. Table 8 shows the predictions and results. Of the possible variants of the salience imbalance predictions, not one yields a significant difference, and in two cases, the trends are in the opposite direction to the predictions. As in Experiment 1, subjects did not include more propositions from the base than from the target, or from the top half of the base than the top half of the target, etc. It does not

Table 8

Results of Experiment 2: Mean Numbers of Predicates Occurring in Metaphor Interpretations

Predictions of Salience Imbalance	Results: Mean Number of Predicates[a]		
B1 ∩ T2 > B2 ∩ T1	B1 ∩ T2 = .025	B2 ∩ T1 = .026	NS
B > T	B = .63	T = .59	NS
B1 > B2	B1 = .37	B2 = .28	NS
T2 > T1	T2 = .23	T1 = .39	NS
B1 > T1	B1 = .37	T1 = .39	NS
T2 > B2	T2 = .23	B2 = .28	NS

[a] Notation: All abbreviations refer to mean number of predicates occurring in a subject's metaphor interpretation that appear also in specified parts of S's object descriptions.

B = N in base description

T = N in target description

B1 = N in top half of base description

B2 = N in bottom half of base description

T1 = N in top half of target description

T2 = N in bottom half of target description

B1 ∩ T2 = N in both top half of base and bottom half of target descriptions

appear that subjects' choice of proposition to include in their metaphor interpretations was determined by salience imbalance. Thus salience imbalance did not appear to function as an interpretation heuristic.

Although salience imbalance did not determine the interpretations, perhaps it determined subjects' perceived metaphoricity. The second prediction of the salience imbalance theory is that the metaphoricity ratings should correlate positively with the degree of salience imbalance. That is, they should correlate positively with the number of propositions that enter into the metaphor from the base, and negatively with the number that enter in from the target. This prediction too is not confirmed. Both of the relevant correlations are nonsignificant, $r(22) = .32$, NS and $r(22) = .10$, NS, for the correlations between rated metaphoricity and number of propositions from base and target, respectively.

Discussion

The adults in this study fit the structure-mapping pattern of transferring relational systems across domains. There are several indications of this pattern. First, adult responses were rated high in relationality overall. Second, when given double metaphors that could support either a relational or an attributional interpretation, adults interpreted them more relationally than attributionally. Third, adults rated the relational and double metaphors as more apt than the attribute metaphors. Fourth, aptness for adults correlates positively with judged relationality, but negatively with judged attributionality. Adults appear both to seek relational predicates in metaphorical mapping and to judge the aptness of the comparison according to the relationality of the mapping.

General Discussion

The structure-mapping theory of metaphor is strongly supported by the results of these two experiments. In Experiment 1, metaphor interpretations were found to be more relational than the object descriptions on which they were based. Not only did subjects tend to base their metaphor interpretations on relational information, but they also appeared to base their aptness ratings on how successful they were in arriving at a relational interpretation. The patterns of correlation suggest that people found metaphors more apt to the extent that they could find a relational system to map from base to target. In contrast, subjects appeared to find attribute matches irrelevant or even detrimental to their sense of how apt a metaphor was. The correlations between aptness and attributionality were negative in Experiment 2 and nonsignificant, but with a negative trend, in Experiment 1. In Experiment 2, the adult subjects produced structural interpretations of metaphorical comparisons when possible, and judged the aptness of the metaphors according to their relationality. This implicit interpretation strategy developed gradually. Indeed, the pattern of results suggests that metaphoric development can be described as the gradual development of relational focus.

The success of the theory raises a number of interesting questions of detail. First, do attributes play any role in analogical processing? The answer is almost certainly yes. There is evidence that attribute-overlap plays a strong role in the spontaneous noticing of potential analogies (Forbus & Gentner, 1986; Gentner, 1983, 1986; Gentner & Landers, 1985; Ross, 1984, 1986) and also in promoting the accuracy of on-line mapping and transfer (Gentner & Schumacher, 1986; Gentner & Toupin, 1986). Given that two domains share relational structure, there is evidence to suggest that

the more attributes that are shared --- that is, the more the match approximates literal similarity --- the more likely the match is to be spontaneously accessible (Gentner & Landers, 1985; Reed, Ernst & Banerji, 1974; Gick & Holyoak, 1980, 1983).

Salience imbalance reconsidered. These results provide no support for the strong predictions of the salience imbalance theory of metaphor. Experiments 1 and 2 show remarkably similar patterns: in neither experiment is there any significant tendency for the metaphor interpretations to contain high-salient information from the base and/or low-salient information from the target, nor is there any correlation between metaphoricity and salience imbalance.

Some of the negative results might be discounted on the grounds that order-of-mention is not a perfect indicator of salience imbalance. It may be that order-of-mention is affected by multiple variables and therefore does not reflect the precise salience order. Thus, the failure of predictions concerning the relative contributions of top-half-of-target versus bottom-half-of-target may be suspect. But there are two indications that the failure of the salience-imbalance predictions is more serious. First, the detailed patterns of negative results are nearly identical for Experiments 1 and 2, which weakens the view that order-of-mention is simply a noisy measure. Second, the salience-imbalance predictions fail not only on the precise order comparisons but also on the overall comparison of the relative contribution of base versus target: There was no tendency for subjects to include more information from the base than from the target in their metaphor interpretations. By any reasonable interpretation of the notion of salience, it seems fair to assume that subjects included at least some information in their object descriptions that they considered salient

for the objects. This view is informally supported by examination of the descriptions, as exemplified in Table 2. Yet in neither experiment did the base contribute more to the metaphor interpretation than the target. The salience imbalance predictions fail both at the fine-structure level and at the global level of base versus target.

Another indication that salience imbalance is not defining of metaphor is that asymmetry effects also occur in literal similarity comparisons (Rosch, 1973, 1975; Tversky, 1977). For example, Rosch (1973, 1975) demonstrated directional preferences based on typicality differences within categories: thus, "Pink is virtually red." is preferred to "Red is virtually pink." Thus, asymmetry is not specific to metaphor. However, we can still ask whether the degree of asymmetry is greater for metaphor than for literal similarity. The evidence is not clear on this point. For example, Conner and Kogan's (1980) developmental investigations of directional preferences case doubt on an asymmetry difference between metaphor and literal similarity. Subjects were simultaneously shown the base and target objects, in either pictorial or verbal form, counterbalanced for left-right order. Their task was to use them in a sentence of the form "_____ is like _____." Some of the materials involved literal similarity comparisons such as "bicycle/car," within categories such as color, number and common objects, for which Rosch (1973, 1975) has demonstrated directional preferences. Other were metaphors, such as "boxer/charging bull." For each item, a measure of asymmetry was computed from the degree to which subjects agreed on the order of objects -- i.e., on the assignm,ent of base and target. Adults in these studies do indeed show asymmetric patterns of preference (Conner & Kogan, 1980); but there is no evidence for more asymmetry in metaphors than in literal similarity. Indeed, Conner (1983) found less

asymmetry in the adult order preferences for metaphor than for some of the literal similarity categories. Ortony, Vondruska, Foss & Jones (1985) found a different result: in their studies, metaphor exceeded literal similarity in degree of asymmetry. Their method was to present the forward and reversed comparisons together and ask subjects to judge which direction was preferable. Subjects showed stronger order preferences for similes than for literal similarity statements. It appears that relative degree of asymmetry may be difficult to establish.

Probably one reason Ortony et al obtained stronger asymmetry results than Conner & Kagan was their use of simultaneous forward-reversed pairs, which called attention to the order of terms. Ortony et al (1985, p. 575) note that when pilot subjects were asked to process the reversed similes without seeing the forward order, they tended to spontaneously re-reverse them and treat them like forward comparisons. This suggests that, while the notion of salience imbalance may capture a genuine order preference, it is not an interpretation beuristic, or at least not a decisive one. For if the interpretation rule were 'find high salient features in the target' functioned as the chief interpretation rule, then the interpretations would simply follow the order of terms. Instead, other factors more important in determining subjects' interpretations. These patterns are compatible with the present findings, which subjects appeared to follow structure-mapping rules and to disregard salience imbalance in cases of conflict. This suggests that the major interpretation rule for metaphors and analogies is to seek for the best predicate match -- i.e., the most systematic relational structure common to base and target.

Salience imbalance does not appear to describe how people interpret metaphors, nor does it predict metaphoricity or aptness. Thus the strong

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claims - (III) salience imbalance as interpretation heuristic and (II) salience imbalance as defining of metaphorcity - do not appear to hold. Nevertheless, this does nt invalidate the central intuition that metaphors tend to show salience imbalance. There still remains the fact that people prefer metaphors in forward order, and that in general a forward metaphor has a different emphasis - if not a different meaning - from the same metaphor in a reverse direction (Ortony, 1979; Ortony, Vondruska, Foss & Jones, 1985). Glucksberg (1980) has suggested that these order effects in metaphor may be a heightened version of a general feature of language use. By this account, directionality arises from a conversational contract--from shared expectations of speaker and hearer, similar to the conversational postulates of Grice (1975), or to the given-new contract of Clark & Haviland (1977). By this analysis, the salience-imbalance rule is the application of a conversational cooperativenes rule to comparatives. For a sentence "X is (like) Y" to be informative about X, we require that whatever is to be conveyed about X should be more apparent for Y than for X. The rule is, roughly,

> If X is to be explained by comparison with Y,
> then the explanation should be more
> accessible for Y than for X.

Ortony and his colleagues in their recent work offer a similar pragmatic explanation for the salience imbalance phenomenon (Ortony, Vondruska, Foss & Jones, 1985). They state that when a speaker uses a simile such as "a is like b" the hearer has certain pragmatic understandings about what is likely to be conveyed: "...In similes (and indeed in all similarity statements) the "given" entity is the topic of the comparison and therefore is in the a-position. The "new" information that is being communicated about the given entity is contained in the b-term in the sense that it is a

subset of the b-term's attributes. Persumably, to convey the new information, a speaker selects a b-term for which the attributes to be communicated are highly salient. For this reason the b-term is likely to be a good example of something possessing those attributes..."

Perhaps the best summary of the phenomena would be that salience imbalance is about a pragmatic contract on the part of speaker and hearer, while structure-mapping is about the computational semantics of metaphor--the kinds of predicate matches that define the kinds of analogies and that is, i.e., about structure-mapping captures people's beliefs about what constitutes an analogy or metaphor, while salience imbalance captures people's understanding of how this information should be presented.

Knowledge representation in theories of metaphor and analogy. Theories of metaphor and analogy differ in how they differentiate the interpretation rules for metaphor from those for literal similarity. (By interpretation rules I mean the rules by which the interpretation of a metaphor is derived from the stored conceptual representations of its terms.) Underlying many of these disagreements are differences in the kinds of domain representations that are assumed to be the format for mentalese. Three different representational formats have figured in theories of metaphor: multidimensional-space representations, featural representations, and propositional representations. Let us take these in turn. In Tourangeau and Sternberg's (1981) model of metaphor, the mode of representation is that of multidimensional spaces. Like the Rumelhart and Abrahamson (1973) model of analogy, this theory is based on the notion of constructing parallel vectors in multidimensional spaces (Tourangeau & Sternberg, 1981). A metaphor such as "Brezhnev is a hawk" is a mapping from the base subspace (birds) to the target subspace (political figures). It is understood by

constructing an ideal vector from the origin within the target subspace that is parallel to the original vector from origin to hawk in the base subspace. The fit of the metaphor is then given by the distance between the ideal comparison concept found at the terminus of the target vector and the actual target term. The closer the within-space fit and the greater the between-space distance, the more apt the metaphor will be. Thus, "Brezhnev is a hawk" is reasonably apt, because the between-space distance between birds and political figures is fairly large, while the within-space dimensional positions of hawk and Brezhnev are quite close.

Tourangeau and Sternberg (1981) found some support for the theory, particularly for the within-space predictions. They compared subjects' aptness ratings for metaphors with the within-space and between-space distances obtained from similarity ratings on the items. As predicted by their theory, there was a negative correlation between the aptness of a metaphor and the within-space distance between its terms, although the predicted positive correlation between aptness and between-space distance was not obtained.

Tourangeau and Sternberg's theory has in common with the structure-mapping theory the notion of mapping between domains and an empnasis on aptness as crucial to an understanding of metaphor. But the use of a multidimensional space as a representational format poses a sharp limitation on the vocabulary of relations that can be expressed. In the multidimensional space framework, the only relations that can be expressed are comparative adjectives, which are implicitly represented by relative positions along a dimension. For example, LARGER-THAN (x,y) is implicitly represented if x if to the right of y on the size dimension. But most n-place predicates, notably relational predicates such as COLLIDE (x,y), are

not expressible.[9] Leaving aside first-order relations, multidimensional spaces have no mechanism for representing higher-order relations such as CAUSE or IMPLIES. By the present thesis, such predicates are crucial to complex analogy and metaphor, for they express systematicity. Thus, the knowledge representation sharply limits the scope of the theory.

Featural representations. The most prominent featural theory is Ortony's salience imbalance theory (1979).[10] The key explanatory principle in Ortony's theory is salience imbalance: Metaphoricity depends crucially on the relative salience of the matching features in base and target. As we have seen, despite the attractiveness of Ortony's intuitions concerning dirActionality in metaphor, the salience imbalance principle is not defining of metaphoricity. Rather, it appears that Ortony's salience imbalance theory captures some important pragmatic aspects of metaphor. But, like the multidimensional space approach, it is limited by its representational assumptions. In salience imbalance theory, all predicates are treated alike and there is no representational means for explicitly representing relational structure. Thus, though the theory does not rule out interrelationships among objects, it has no way of specifically focusing on relations, much less on systematic sets of relations. Although the problem is not as serious as for multidimensional space representations

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[9] We could express this relation by creating a binary dimension of COLLIDE-WITH-y and placing x on the + value of the dimension; but this would have to be a totally separate dimension from, for example, COLLIDE-WITH-z. If such representations were used, there would of course be no way within the theory to extract the COLLIDE relation from its argument.

[10] As noted before, relations are not excluded from Ortony's componential representations; but they are not structurally differentiated from attributes. So, for example, a feature list for apple, might include "RED, CAN-BE-EATEN, GROWS-ON-TREES...."

still undifferentiated feature list has no way to model a specific focus on relational structure. Ultimately, I believe that theories of metaphor based either on undifferentiated feature lists or on multidimensional-space representations cannot capture the semantic computations involved in analogy and metaphor. To do so, a knowledge representation must be able to explicitly express relations and higher-order relations.

However, structure-mapping and salience imbalance are not incompatible. Rather, they seem to be dealing with different aspects of metaphor comprehension. Structure-mapping characterizes the kinds of semantic information that gets computed and the computational steps necessary to get this information. Salience imbalance may characterize our default pragmatic expectations about how the information should be presented.

Structural representations. The structure-mapping theory (Gentner, 1980, 1982, 1983, 1986; Gentner & Gentner, 1983) assumes a propositional representation. Like featural approaches, it is componential, but there are assumed to be structurally different kinds of components, which play different roles in the interpretation process. Analogy and metaphor are differentiated from literal similarity by a distinction in kind among the shared and nonshared components:[11] object-attributes are left behind, while relations, particularly those that participate in a higher-order relational system, are mapped across. Aside from the psychological evidence presented

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[11]It is interesting that Tversky's (1977) theory of literal similarity appears to succeed without making such distinctions; an undifferentiated featural approach seems to suffice for many aspects of literal similarity. The difference, I suspect, is that, in literal similarity, there is enough overlap of all kinds of predicates to allow us to ignore structural distinctions, at least for some purposes; whereas, in metaphor and analogy, the relational structures stand alone, and therefore must be delineated.

here, there is computational support for these ideas. A computer simulation of the theory, called the Structure-mapping Engine, written by Brian Falkenhainer and Ken Forbus, produces psychologically reasonable interpretations of analogies and relational metaphors (Falkenhainer, Forbus & Gentner, 1986; see also Gentner, Falkenhainer & Skorstad, 1987).

Analogy in artificial intelligence and in cognitive science is converging on the use of such structurally differentiated representations to model complex explanatory analogies. One early treatment of complex analogies was Moore and Newell's (1973) Merlin system, which featured a mechanism for "viewing x as y" based on explicit comparisons ofthe shared and nonshared predicates of two situations. Winston (1980, 1981), using a propositional representation system, has simulated the process of matching a current situation with a previously stored precedent and using the similarity match to justify importing inferences from the precedent to the current situation. An extremely interesting aspect of Winston's work is his modeling of the process of abstracting general rules from analogical matches. As in the structure-mapping account, not all predicates are equally important in evaluating an analogical match. Winston uses a slightly more specific version of the systematicity principle to select the predicates that matter: in his account, the match between the base and target is performed by counting only those predicates that occur in causal chains. This requirement is somewhat more restrictive than the structure-mapping principle that participation in any constraining higher-order chain results in preferential mapping. However, it has a similar effect of focusing the matcher on systematic relational structures rather than on haphazard resemblances between situations. Other artificial intelligence research, notably that of Burstein (1983) and Carbonell (1981, 1983) has

emphasized the role of common goals and plans as organizing principles in analogy. Holyoak (1985) has also advocated a goal-centered propositional approach to analogy. In a different vein, Hofstadter's (1981, 1984) research aims to provide a computational model of the aesthetics of analogy.

There are also a number of psychological treatments of analogy that are based on propositional representations of knowledge. Miller (1979) has set forth a detailed and elegant analysis of the interpretation of metaphor. Rumelhart and Norman (1981) used a schema-based representational system to discuss analogical transfer, applying this framework to phenomena of learning in language and in mathematics. Other research, although not necessarily focusing on explicit representation, has explored the psychology of complex analogies using a schema-like propositional framework (Gick and Holyoak,1980, 1983; Schustack & Anderson, 1979; Verbrugge & McCarrell, 1977).

Finally, studies of analogy in scientific learning and in reasoning have emphasized the importance of shared complex representational structures [Alement, 1981, 1982; Collins & Gentner, in press; Gentner, 1980; Gentner & Gentner, 1983; Gentner & Schumacher, 1986; Hesse, 1966; Hobbs, 1979; Hoffman, 1980; Oppenheimer, 1955; Polya, 1973; Riley, 1981; Rumelhart & Norman, 1981; Stevens, Collins & Goldin, 1979; VanLehn & Brown, 1980). VanLehn & Brown (1980) analyzed analogical learning of procedural rules in arithmetic, postulating mapping rules whereby procedures can be transferred from one domain to another. Although the details of these accounts vary, there is a fair degree of agreement on the major principles. In the main, these accounts are compatible with the structure-mapping account: some kinds of high-order predicates tend to be preserved across domains with dissimilar low-order predicates.

The act of abstracting relations away from the objects to which they apply is, at its best, one of the great cognitive achievements of an individual or a culture. In Russell's words, "It must have required many ages to discover that a brace of pheasants and a couple of days were both instances of the number two." Research in analogy and metaphor may provide a way to understand this achievement.

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